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The education of hydrologists
(Report of an IAHS/UNESCO Panel on hydrological education)

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PREFACE by the IAHS President

In the late 1987, I began discussion on the education of hydrologists with Dr S. Dumitrescu, Director of the Division of Water Sciences of UNESCO. Our concern is reflected in the following two excerpts from the related correspondence:

"...There has been a growing awareness that hydrology as a geophysical science is making slow progress and has no solid foundations. A major (or perhaps the major) factor in this unsatisfactory situation is the fact that the majority of hydrologists are not trained as scientists but as technologists. It seems self-evident that a science cannot be founded on a technological education. Hence, if we are not paying merely lip-service to the science of hydrology, we should make an effort to provide it with an adequate educational basis ..." (Klemes)

"...I fully agree with you that the time has come to better define the position of hydrology as a geophysical science, its relations with other..."
environmental sciences and with engineering sciences concerned by water resource development and management, and – in this light – determine the educational requirements for hydrologists ..." (Dumitrescu).

As a result of these discussions, an IAHS/UNESCO Panel was established in 1989 to address the question of the intellectual content and context of hydrological education and to make recommendations accordingly. The Panel subsequently adopted the following terms of reference:

"To consider whether the education of hydrologists is suffering from a lack of recognition of the natural science base of hydrology and, if deemed necessary, to make proposals for new emphases in the organization, structure and content of university education of hydrologists, within the ambit of geoscience and of applied professional practice".

The Panel members were:
Professor J. E. Nash (Chairman), University College Galway, Ireland;
Professor P. S. Eagleson, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA;
Dr J. R. Philip, Commonwealth Scientific and Industrial Research Organization, Canberra, ACT, Australia; and
Professor W. H. van der Molen, Agricultural University, Wageningen, The Netherlands.

The Panel was assisted in its work by Dr J. S. Gladwell and Dr V. Klemeš, representing UNESCO and IAHS respectively.

The Panel met twice at the Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, in 1989 and once at University College Galway, Ireland, in 1990 and summarized the results of its deliberations in this report.

On behalf of IAHS and UNESCO, I would like to express my thanks to the Panel members for their dedication to the difficult task imposed on them and to its Chairman for his patience and determination in guiding the Panel in its work. Also, I would like to thank UNESCO for carrying the main burden of the Panel sponsorship and the two aforementioned universities for hosting the meetings.

V. Klernes
President, IAHS

INTRODUCTION

There is a widespread unease among hydrologists that in the past forty years the practice of hydrology as a technology for the solution of the problems arising in water resources development has not progressed adequately. Most of the problems recognised at that time remain with us today and, when they arise in individual cases, their solution is usually approached in an empirical way drawing little on the principles of natural science. Perhaps because of the failure of technologists to found their technology on a sound scientific basis, the science too has been slow to develop – thus in a sense seeming to justify its neglect by the technologist. It would seem that this vicious circle can be
The Education of Hydrologists

broken only by a thorough review of the science and technology of hydrology and a reassessment of the manner of education of hydrological scientists and technologists.

The main motivation for the study of hydrology in the past was to improve technologies for the development of water resources (water supply, energy production, navigation, flood protection etc.). Initially, these projects were on a small scale, and were independent in the sense of not interfering one with another; thus the more general aspects and interconnections of hydrology could be ignored. More recently, the increasing scale of such projects involved increasing impact on the general water regime and an increasing interference between the projects themselves. This called for increased hydrological awareness though still centred on individual projects. As a consequence, hydrology developed along separate paths determined by the immediate needs of each particular water related technology, such as water supply, urban and rural drainage, power, etc.. Hydrology as a science failed to develop a coherent discipline, and the technology failed to meet the challenges of the new situation.

It is likely that, for the foreseeable future, major problems involving the interaction of man with the hydrological environment on the global scale will increasingly require the attention of teams of scientists from many disciplines, including that of the scientifically trained hydrologist. However, many hydrological problems in the day-to-day design and operation of river control works, groundwater utilization and pollution control will continue to fall within the responsibility of the engineering hydrologist and indeed increased public awareness of the global problems of the hydrological environment will tend to increase rather than reduce interest in hydrological problems at the catchment and smaller scales also, thus increasing further the role of the engineering hydrologist who will no longer feel secure within his traditional domain of open channel and groundwater hydraulics, rainfall/runoff relations, consumptive use and the statistical description of river flow regimes. Already the pressure exists, and recent UNESCO recommendations on the training of hydrologists prescribe more and more extensive courses, most recently advocating an increased awareness of environmental impact.

The challenges to hydrology can be met only through a conscious and concerted effort to consolidate and develop hydrology intensively as a coherent geoscience and as a technology resting on a sound scientific basis. Education is central to the required process of change and improvement. The present structure of hydrological education, generally tailored to the needs of specialized non-hydrological disciplines, is ill-fitted to cope with present and future requirements. On the whole (and with due respect to some honourable exceptions), it does not produce professionals with the background and mix of expertise that are increasingly in demand.

HYDROLOGY AS A GEOSCIENCE

The hydrological cycle, which is the framework of hydrological science, extends across a wide spectrum of space and time scales. Through the storage and
release of latent heat accompanying phase change, the cycle affects the global
circulations of atmosphere and ocean and hence is instrumental in shaping
weather and climate. Water’s efficiency as a solvent makes low temperature
geochemistry an integral part of the hydrological cycle; all water-soluble
elements follow this cycle, at least part way, and all the way for substances
which are volatile as well as soluble. The hydrological cycle is thus the inte­
grating process for the fluxes of water, energy and some chemical substances.

Earth is unique among the planets of the solar system in having an
active water cycle and because it supports life. The water cycle is an essential
part of the planet’s life support mechanism and, to the extent that they are
responsible for Earth’s moderate surface temperatures, the biota permit the
water cycle to exist. This synergism couples the animate and inanimate
components of Earth into an evolving system. The central role of water in
the evolution and operation of Earth’s system provides the rationale for
seeing hydrology as a geoscience, of status similar to that of the atmospheric,
oceanic and solid earth sciences. A more extensive development of this thesis
is to be found in NRC (1990).

As a branch of geoscience, hydrology embraces the totality of physical
processes involved in the hydrological cycle and attendant phenomena, on all
scales, and in the interactions between them. Like other branches of
geoscience it is a natural science, subject to the criteria of natural science,
and advanced by the methods of natural science. Its aim, as is the aim of
natural science in general, is to investigate and understand natural pheno­
mena. It is supported by the basic sciences of mathematics, physics, chemistry
and biology.

Formal recognition as a branch of geophysics was first accorded to
hydrology in 1922 when the International Branch of Scientific Hydrology was
created within the International Union of Geodesy and Geophysics (IUGG),
which had been founded in 1919 to "promote and co-ordinate physical,
chemical and mathematical studies of the earth and its immediate spatial
environment". The Branch was soon transformed into the International
Association of Scientific Hydrology (IASH) which now carries the name of
the International Association of Hydrological Sciences (IAHS) and is one of
the seven associations constituting the IUGG. (The other six are: Interna­
tional Association of Geodesy (IAG); International Association of
Seismology and Physics of the Earth’s Interior (IASPEI); International
Association of Volcanology and Chemistry of the Earth’s Interior (IACVEI);
International Association of Geomagnetism and Aeronomy (IAGA);
International Association of Meteorology and Atmospheric Physics (IAMAP);
and International Association of Physical Sciences of the Ocean (IAPSO).) A
further important step towards the affirmation of hydrology as a geoscience
occurred in 1930 when the American Geophysical Union (AGU) designated
hydrology as its seventh section, the other six paralleling the associations of
the IUGG.

These developments provided a strong impetus for the study of
hydrology as a unified field of natural science and not merely as a tool in the
solution of various ad hoc engineering, agricultural and other water-related
problems.
While the principle of organization provided by the hydrological cycle is convenient for placing hydrology in the context of geoscience, it would be neither practical nor realistic for hydrology to claim as its exclusive preserve all sectors of the hydrological cycle. The atmospheric sector is primarily the province of atmospheric science; the oceanic sector is that of ocean science and the geophysics of ice and snow is the field of glaciology. Thus, although the interfaces with meteorology, oceanography, and glaciology are essential elements of hydrology, its central topic is the terrestrial sector of the cycle.

It is therefore suggested that hydrology be defined within the terrestrial sector of the hydrological cycle, including its interactions with the atmosphere, oceans and glaciers. Its central concern is with water and the land environment but it also embraces, where appropriate, the processes of evaporation, condensation, precipitation, advection, freezing and thawing. Moreover, it addresses the water-related effects on and of life, especially vegetative life.

It must be understood further that the hydrological cycle involves not only the circulation on all scales of water molecules and energy, but also determines the transport and disposition of gases and other molecules and ions in solutions, of suspended particles, and of small organisms living in soil, ground-, and surface water.

A good understanding of the vast array of processes of the natural hydrological cycle of an Earth untouched by man would in itself demand a very considerable effort in natural science. Superimposed on all this, we have the involvement of man, for good or ill, in almost every aspect of the cycle of water and the various entities transported and dispersed by it. Man's intervention leads to many more scientific questions, as well as making a good understanding of hydrological processes all the more urgent.

It is fashionable to regard man's involvement in nature as almost always bad. It is true that ignorance (often spurred on by greed) is leading to progressive damage to the natural environment and that we require as much scientific understanding as possible of the relevant processes in order to diagnose our mistakes and put them right. On a more positive note, however, man's ability to control his environment, to improve it and to make it more enjoyable, and indeed more productive and profitable, depends just as centrally on putting our understanding of hydrological processes on as sound a scientific basis as we can manage.

THE PRESENT STATE OF HYDROLOGICAL EDUCATION

Hydrology as a profession is only rarely granted the recognition of a distinct undergraduate training. As a subject matter it often occurs in the curricula of studies of many courses in applied science and engineering, e.g. meteorology, geology, geography, civil and agricultural engineering and forestry. In some it is treated as a subject of peripheral interest, in others as a source of data for application within a major discipline such as agriculture or forestry, or as a component topic as in geology, where it is usually presented in a rather descriptive and non-quantitative manner. Within undergraduate courses in civil and environmental engineering, those aspects of hydrology which are
immediately relevant to engineering works and practice compete for the attention of students with other topics in already overcrowded curricula.

Hydrology taught in this fragmented manner is necessarily restricted in depth and scope by the needs or interests of the parent disciplines within which it is taught. Graduates of such courses could certainly not be considered appropriately trained as hydrologists.

Students obtain restricted and uneven backgrounds in the science, which limits their general understanding, and hydrology fails to acquire the image of a coherent and comprehensive science that is so necessary, both to attract young minds and to support the scientific infrastructure needed for its continuing evolution.

Postgraduate studies have always provided opportunities, for those who wish to do so, to pursue an interest in hydrology, but such interests have tended to be conditioned by the nature of the primary training of the participant. Civil engineers who pursued an interest in hydrology became engineering hydrologists. Some geologists similarly became hydrogeologists, and so on. Thus the hyphenated hydrologist emerged, before the category of hydrologist itself came to be recognised or defined. It is probably true to say that most of the pioneers of hydrology, and those distinguished hydrologists of the immediate post-war period, had little undergraduate training in hydrology and probably very little formal training in hydrology at any level. The ranks of hydrologists have always been replenished by a drifting in from other disciplines. While this is not an orthodox way in which to build a profession, it must be recognized that many who came to hydrology in this way brought with them a consuming interest, a lively intelligence and sometimes an acquaintance with technologies which were relevant but previously unused in hydrology.

Engineers coming thus to hydrology brought with them the problem-solving ethos of their profession, which conditioned their subsequent studies and endeavours. Often without adequate backgrounds in physics and chemistry, but with strong mathematical bias, they may have tended to neglect the possibility of applying established scientific principles, and the necessity for careful observations. They may have tended to rely excessively on the mathematical analysis of "data", i.e. observations, usually made by other persons, often for other purposes, which were "given" to the engineering hydrologist in the hope and expectation that he might detect some germ of information or expression of a relationship relevant to an immediate practical problem. Thus hydrology came to be practised as if it were a basic science, whose relationships were to be found exclusively by the formulation and testing of hypotheses against observations, rather than equally by the application of established principles of extant natural sciences. This approach, though providing many interesting challenges, which often left room for an almost Renaissance exercise of ingenuity in problem solving, was not, however, a sound basis on which to build an applied science.

More significantly, however, engineering hydrologists undoubtedly fell into the error of preferring the means to the end and of learning, modifying and adapting the techniques of analysis often to a degree of sophistication far beyond what would be justified by the nature of the observations to which these tools were applied. Much of this intellectual effort was entirely
irrelevant to hydrological science and divorced from the practice of the hydrological profession.

By the 1970s, expanding dependence upon water resources development, and an expanding consciousness of environmental problems, brought about a recognition of the need for appropriate educational modes both in the science and the profession of hydrology. Without any clear distinction between the scientific and the professional, postgraduate courses in hydrology and in water resources development were instituted at a number of universities throughout the world, often with the support and sponsorship of UNESCO and the World Meteorological Organization. Some courses were of short duration and confined to specific topics within the overall water resources or hydrological context; others, with durations of one or two years, were intended to be "conversion kits" or "topping up" courses in general hydrology for suitably trained graduates in other disciplines. These relied upon the prior training of the participants to provide the necessary basis for a mixed professional and scientific development. Chandra & Mosterman (1983) and Ayibotele (1988) provide guides to the material for such courses recommended by UNESCO.

Recently, under the impetus of concern for global change, the geoscience community has realised the central role of the water cycle in the operation of the Earth's system and has begun to introduce more hydrology into the preparation of its postgraduate students. This is occurring primarily in departments of geological science, around issues of the role of groundwater in tectonics; and in atmospheric science and around the influence of land use upon climate and weather. This trend is likely to continue as postgraduate educational programmes in the multidisciplinary science of Earth system behaviour become more common.

One urgent educational problem, which has reached crisis proportions in many universities, is the lack of field and laboratory experience. This is a problem at all levels and in many disciplines and has existed for long enough to become self-perpetuating through the next generation of faculty. The consequences in hydrology are both profound and disturbing especially with the current emphasis on conceptual modelling. Although such models constitute useful tools in the investigation of the physical world, exclusive or undue reliance on them may tend to separate students from the realities they are supposed to study. In the absence of appropriate testing, models take on an aura of reality in the minds of their users and become a source of unsound science and practice.

The more one considers hydrology as a profession rather than as an applied science the less tolerable the present educational system becomes. Applied scientists are accustomed to a broad undergraduate training and later specialization. The more clearly identified professions, however, require specialization even at the undergraduate level.

EDUCATION FOR ADVANCEMENT OF THE SCIENCE

In the above Sections, the scope and content of hydrology as a geoscience have been indicated, and current hydrological education has been assessed and
found to be fragmentary and deficient in providing integrated perspectives on, and insights into, hydrology as a whole. In this Section a structure and content for hydrological education which seek to remedy these shortcomings by promoting the development of hydrology as a science are proposed. The next Section deals with the distinctive educational requisites for professional practice.

**Undergraduate education**

There is a need for undergraduate education designed to raise hydrological consciousness in preparation for graduate-level study in the geosciences with emphasis on hydrological science. The undergraduate preparation should, of course, provide the fundamentals of mathematics, chemistry, biology and physics, including thermodynamics, probability and statistics, and fluid dynamics. In addition, it should provide a basic understanding of the Earth system and, for this reason, should probably take place in university departments of Earth Science. The subject matter should include first courses in geology, ecology, meteorology, oceanography and hydrology. It should be presented in a manner that gives explicit attention to hydrological science by introducing students to such topics as quantitative aspects of the hydrological cycle at all scales, the coupled flux of heat and moisture at soil/vegetation, snow/ice, and water surfaces, the roles of precipitation and evaporation in atmospheric and oceanic dynamics, the role of water in shaping the Earth’s surface, the movement of water in the Earth’s crust, global hydroclimatology, and the role of water in life.

**Graduate education**

The demand for PhD level hydrological scientists to fill teaching and/or research positions is (and probably will remain) small, perhaps at present of the order of one hundred per year worldwide. In addition, the interdisciplinary nature of the science requires advanced academic offerings over a wide range of fields. For these reasons, it is unlikely that many separate departments of Hydrological Science will arise. Rather, the demand will be met by those universities which support *ad hoc* programmes assembled from several departments providing an adequate coverage of the broad hydrological field and a deeper concentration on a part of that field.

Subjects covered broadly should include mathematics, chemistry, biology and physics to at least one course further than the corresponding undergraduate programme. Such material as advanced mathematics, stochastic processes, aqueous geochemistry, plant physiology, radiation physics and geophysical fluid dynamics should be included.

Depth in a chosen field may be obtained through additional study, including field experience and a dissertation on some systematic specialisation such as:

hydrology and the earth's crust: groundwater and the associated heat and mass transfer, etc.;
The Education of Hydrologists

hydrology and surficial processes: unsaturated zone dynamics, evapotranspiration, snowmelt, etc.;
hydrology and geomorphic processes: erosion, transport, deposition and fluvial hydraulics, geomorphology, etc.;
hydrology and climatic processes: global water balance, interaction of land surface and climate, advection, paleohydrology, etc.;
hydrology and weather processes: space-time precipitation, flash floods, interaction of land surface and mesoscale weather systems, etc.;
hydrology and biological processes: relationships between vegetation patterns and climate, metabolism and energetics of microbial communities in water, etc.; and
hydrology and chemical processes: geochemical characterizations of surface and groundwaters, etc..

THE EDUCATION OF THE APPLIED (OR ENGINEERING) HYDROLOGIST

Present typical postgraduate topping up courses in hydrology do not provide an adequate preparation for the future role of the scientific or applied hydrologist nor can such a preparation be provided by a mere extension in the duration or subject matter of the present courses. Their defect is in the lack of depth of treatment rather than the narrowness of the subject matter and their failure to convey the richness of the totality of hydrological interactions.

Changes in the organization and content of university courses in applied hydrology will probably be evolutionary rather than abrupt. The suggestion of a full undergraduate course in engineering hydrology is discussed in "Curricula and Syllabi in Hydrology", UNESCO Technical Paper 22, whose authors conclude that this is unrealistic. They state that:

"For the immediate future, however, and, in many countries for the foreseeable future, the normal method of training professional (engineering) hydrologists will continue to be by way of postgraduate courses designed to "top up" existing training usually in an appropriate branch of engineering or to convert a science graduate".

The present panel agrees, but believes it is important to stress the directions in which the training of applied hydrology should evolve:

(a) An effort should be made to increase the hydrological content of bachelor degree courses, thus increasing motivation and providing appropriate background for subsequent postgraduate training in applied hydrology and related research.

(b) Present postgraduate courses should be examined critically with a view to providing an increased content of basic science, and a greater variety of hydrological sub-fields. A conscious effort should be made to introduce experimental and observational content into the courses and to eliminate any naive dependence on analysis.

(c) Efforts should be made to ensure that the developments in hydrological science achieved in geoscience departments are made readily available to
the applied hydrologists, typically in engineering departments. Close contact should be established by joint appointments, visiting lecturers and possibly by geoscience departments offering some courses specifically for engineering hydrologists.

**SUMMARY AND RECOMMENDATIONS**

The major inadequacies of present-day hydrology are:

(a) methodological deficiencies;
(b) the slowness and unevenness of the advance of our scientific understanding of hydrology though research; and
(c) the slow diffusion of knowledge from research to practice.

The Panel believes that a conscious effort to strengthen education in hydrology is the primary means open to us to remedy these deficiencies. In broad terms, it sees the aims and content of education in hydrology at the university level as:

(a) to develop and improve awareness of the totality of interconnected (mainly physical) processes involved in the hydrological cycle;
(b) to provide the maximum possible training in relevant areas of the basic scientific disciplines underpinning hydrology;
(c) to develop the connections between those basic disciplines and the scientific study of various hydrological processes;
(d) to stress the central roles of observation and experimentation in the scientific study of hydrology;
(e) to develop more fully and clearly the connections between scientific knowledge of hydrological processes and the current (and potentially improved) professional practice of hydrology.

In the light of the above, the Panel makes the following recommendations:

(a) Undergraduate education, such as now occurs typically in university departments of Earth Sciences, should give explicit attention to hydrology as an integral component of geoscience with sufficient depth and coverage to motivate students to pursue hydrology as a career. The programme should include the introduction of topics such as the global hydrological cycle, the coupled flux of heat and moisture at soil/vegetation, snow/ice, and water surfaces, the roles of precipitation and evaporation in atmospheric and oceanic dynamics, the role of water in shaping the Earth's surface, global hydroclimatology, and the role of water in life.

(b) Universities should consider the establishment of the institutional mechanisms and academic offerings necessary to the support of multidisciplinary PhD programmes in hydrological science. These would differ due to local tradition and constraints and might vary from separate Departments of Hydrological Science to ad hoc programmes assembled from across the institution to address different hydrological topics.

(c) Present postgraduate professional courses in hydrology should be examined critically with a view to providing for greater emphasis on the basic sciences and a greater variety of hydrological sub-fields. A conscious effort should be made to introduce experimental and
observational material into the courses.

(d) Every effort should be made to ensure that the developments in hydrological science made in geoscience departments are made available to students of applied hydrology. Close contact between the two streams should be established by joint appointments, visiting lecturers and possibly by geoscience departments offering some courses specifically for engineering hydrologists.

(e) Hydrological instruction in applications areas, such as Civil Engineering, Agricultural Engineering, Environmental Engineering and Forestry, should be modified to increase their basic science content.

REFERENCES

